

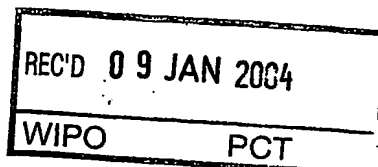
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Beneden Oosterdiep 27  
NL-9641 JA Veendam  
PAYS-BAS

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Potatoes with increased protein content

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The invention relates to the breeding and selection of potatoes.

Apart from being an important staple food, potato is classically the raw material for industrial production of starch from potato tubers. Furthermore, these days, the industrial harvest of potato protein from potato tubers, earlier seen as a *quantité négligeable*, attracts more attention considering the increased value given to vegetable protein sources, for example for animal food, if only as a side product accompanying starch production. Where, chemically, potato starch in potato tubers essentially consists of two components: amylopectin and amylose in a proportion of approximately 80% to 20%, potato proteins in tubers essentially consist of protease inhibitors that help protect the tuber against disease such as parasite infestations or fungal or bacterial rot and storage proteins such as patatin in a proportion of approximately 60% to 40%.

For various reasons, starch producers prefer potatoes with different ratios of amylopectin and amylose. An earlier induced gene mutation in potatoes that affects the synthesis of the enzyme granule bound starch synthase (GBSS), and the subsequent molecular cloning of this gene (Hovenkamp-Hermelink et al., 1987, Theor. Appl. Genet. 75:217-221; Visser et al., 1989, Plant Science 64:185-192) has opened possibilities for altering the starch composition of potatoes – either through established breeding methods or through modern techniques of genetic manipulation.

The GBSS mutation in potato is similar to the so-called waxy (*wx*) mutation in maize and prevents the production of amylose, when expression or specific function of the GBSS protein is absent. Therefore, this mutation has been designated as amylose-free (*amf*) mutant of potato. Herein, the *amf*-gene mutation stands for a modification of the GBSS-gene that leads to a complete functional loss of GBSS-activity, notwithstanding that GBSS-like gene products, without the specific activity, may still be expressed from the gene's transcripts in question, whereby the *Amf*-gene stands for a gene from which gene products with GBSS-activity can still be obtained. The *amf*-gene character is determined by a

monogenic mendelian recessive gene, the phenotype of which can be detected in various plant parts such as columella cells of root tips, tubers, plastids in the stomatal guard cells and in microspores (Jacobsen et al., 1989, Euphytica 44:43-48). When these parts are stained with a potassium iodine solution (Lugol),

5 starch is stained red in mutants and dark blue in the wild type.

Unlike many other phenotypic genetic markers, the mutated or functionally deleted GBBS- or *amf*-gene offers certain special advantages for genetic analysis as well as for breeding. For example, the progeny can be classified at a very early seedling stage as well as in adult plants, through pollen staining, homo- and

10 heterozygotes can be unambiguously classified: the dosages 2-4 of the mutant allele in a tetraploid can be easily detected through the ratios 5:1, 1:1 and 0:1 in stained pollen samples; different types of 2n-gametes in diploid clones can be detected and their influence on the phenotype and genotype of tetraploid from 4x\*2x crosses can be predicted.

15 Prospects of using the material in conventional as well as in analytic breeding of potato have since the development of the *amf*-gene potato mutant of Hovenkamp-Hermelink been opened. A disadvantage for breeding is the recessive nature of *amf*, which complicates the combination of this character with other agronomic traits at the tetraploid level.

20 Therefore, the analytic breeding method advocated by Chase (1963, J. Genet. Cytol. 5:359-364), which involves breeding of potato at the diploid level and returning to the tetraploid condition through the use of 2n-gametes, could be of considerable value for breeding *amf*-varieties. The aim of such investigations are at least two fold: a. to combine *amfamf* and *Amfamf* genotypes with that of 2n-gamete formation, and b. to create fertile, nulliplex clones as basic material for

25 breeding amylose-free potatoes. On the other hand, development of suitable diploid material that produces high frequencies of 2n-pollen and 2n-eggs would also open the way for unilateral and bilateral sexual polyploidization (Mendiburu and Peloquin, 1976, Theor. Appl. Genet. 48:137-143). Such diploid breeding

30 material may be homozygous (*amfamf*) or heterozygous (*Amfamf*); because in both cases selection can be carried out based on pollen phenotype.

The invention relates to the breeding and selection of potatoes. Surprisingly, it was found herein that potatoes with at least one *amf*-allele background have a

35 distinct phenotypic advantage when compared with potatoes having a similar

genetic background lacking the *amf*-gene. One such advantage relates to protein content. Genotypes that are nulliplex for the *Amf*-allele, i.e. for diploid plants the *amfamf* (aa) and for tetraploid plants the *amfamfamfamf* (aaaa) genotypes display said advantage even stronger.

5           The invention provides a potato plant or part derived thereof (such as a cell, a protoplast, a tuber, an embryo, a seed or an explant) having at least one *amf*-gene said potato plant or part further provided with an increased capacity to store a protein (herein also identified as a high protein potato) as characterized by a total raw protein content of its tubers (preferably as determined in the  
10 potato juice derived thereof) at least 1.9% m/m, more preferred at least 2.3% m/m, most preferred at least 2.7% m/m. Within a potato homozygous for the *amf*-allele as provided herein, i.e. an amylose-free high protein potato, such increased capacity to store protein is most fully developed. The inventors have gathered the surprising insight that depriving a potato of GBSS-activity allows for increasing  
15 protein storage in said potato, provided it has the genetic capacity to produce increased, or at least sufficient, amounts of said protein. Potatoes comprising a *amf*-allele have essentially higher protein storage capacity than potatoes of otherwise similar genetic background having no *amf*-gene. Potatoes homozygous for the *amf*-allele are, speaking from the viewpoint of protein storage, preferred.

20           Originally, the *amf*-mutation was induced in a monohaploid which had been selected only for flowering (Hovenkamp-Hermelink et al., 1987, *ibid*) but not for fertility and agronomic characters. Therefore, in order to incorporate this recessive mutant in other potatoes the inventors crossed the diploid genotype derived from the monoploid mutant clone with agronomically more desirable  
25 clones which, however, have the wild type of the *Amf* gene. As a first step in this process, fertile diploids that are homozygous for the mutant character (*amfamf*), were produced. When these diploids are somatically doubled through in vitro adventitious shoot regeneration, the resulting tetraploids proved to be less fertile (both male and female). However the 4x plants obtained through meiotic  
30 doubling – using 4x x 2x crosses- gave rise to fertile nulliplex tetraploids. Thus, in spite of high levels of sterility and expression of lethal factors in the initial stages, more fertile and vigorous diploid and tetraploid breeding material were created with the desired *amf*-genotypes. Availability of vigorous, fertile and agronomically useful tetraploid genotypes than led to conventional breeding of  
35 *amf*-mutants of potato. It was than surprisingly found that *amf*-mutants,

resulting from crosses with wild-type potatoes had increased storage capacity for proteins in their tubers, these days considered an economically desirable trait.

It is preferred that said high total raw protein content is also reflected in the amount of protein that can be harvested, e.g. from the tubers. Such measure is given by identifying the fraction of coagulating protein available for harvest, as further explained in the detailed description. The invention also provides a potato plant or part derived thereof (such as a cell, a protoplast, a tuber, an embryo, a seed or an explant) having at least one *amf*-gene said potato plant or part further provided with an increased capacity to produce harvestable protein as characterized by a total coagulating protein content of its tubers (preferably as determined in the potato juice derived thereof) at least 0.9%, more preferred at least 1.2%, most preferred at least 1.5%. Considering that high protein levels are these days often more profitable than high starch levels, the invention also provides a high protein potato (i.e. with more than 1.2%, preferably more than 1.5% coagulating protein in its tubers) characterized in that its tubers essentially show a coagulating protein versus starch ratio of at least 45 kg/ton, more preferred of at least 90 kg/ton.

Furthermore, the invention provides a high-protein potato according to the invention characterized in that it is an transgenic potato, for example provided with a gene or gene encoding for a heterologous protein, for example with the purpose to provide a high protein potato according to the invention additionally provided with increased levels of essential amino acids. It is preferred that such a heterologous protein comprises a heterologous protein rich in essential amino acids. About half of the 20 amino acids found in proteins can be made by vertebrates; the others must be supplied in the diet. For this reason, the latter are called essential amino acids. These include the strictly essential amino acids which are lysine, leucine, isoleucine, valine, phenylalanine, methionine, threonine and tryptophan. Additionally, tyrosine and cysteine, although they are not strictly essential, must be considered as such, since they are synthesised only from essential amino acids: tyrosine from phenylalanine and cysteine from methionine. In particular, humans and other monogastric animals cannot synthesise the essential amino acids and need to obtain these from their diet. The diet of humans and livestock is largely based on plant material. However, several of these essential amino acids are often only present in low concentrations in crop plants, which mainly constitute said plant based diets. In particular, lysine,

threonine, methionine or tryptophane often lack in such diets. Dietary proteins are often not nutritionally equivalent, which correlates with the amino acid composition of the different proteins. Feeding a diet that provides an inadequate amount of one of the essential amino acids leads to negative nitrogen balance, since the normal catabolism of proteins continues, but new synthesis for replacement is limited by the relative lack of the essential amino acid. This occurs even when the total dietary intake of protein is apparently adequate. The extent to which a dietary protein can be used for the synthesis of tissue proteins is limited by the content of the essential amino acid that is present in an amount relative to the requirement. This is the limiting amino acid of that protein. Now that a high protein potato is provided it is beneficial to use this for the expression and storage of valuable proteins. The invention furthermore provides a transgenic potato cell with at least one *amf*-allele having been provided with a nucleic acid encoding a proteinaceous substance, a sink protein. In a preferred embodiment, said cell accumulates said sink protein up to more than 2%, preferably 4%, or even more than 5% to more than 7% of the total protein content of said cell. The protein preferably contains a high content of essential amino acids (preferably methionine, cysteine, lysine, threonine, or tryptophane). In a preferred embodiment, the invention provides a high protein potato according to the invention comprising a heterologous protein rich in essential amino acids such as listed in Table 4.

The invention also provides a method for breeding and selecting a potato with an increased capacity to store a protein comprising crossing a first parent potato with at least one *amf*-gene with a second parent potato without an *amf*-allele, and selecting progeny for the presence of at least one *amf*-allele and for a protein content of its tubers higher than detected in said first parent or said second parent. It is preferred that progeny is selected for a protein content of its tubers higher than detected in said first parent and said second parent. Of course, the storage of proteins being most fully enhanced in amylose-free plants, it is most preferred to select progeny homozygous for the *amf*-allele.

In a preferred embodiment, the invention provides a method for breeding and selecting a potato with an increased capacity to store a protein comprising crossing a first parent potato with at least one *amf*-allele with a second parent potato without an *amf*-gene, and selecting progeny (preferably homozygous for the *amf*-allele) by testing it for the presence of at least one *amf*-gene and testing

it for total raw protein content with a method, such as the Kjeldahl method as described herein, to determine total raw protein content of its tubers and selecting progeny with a total raw protein content higher than detected in said first parent or said second parent, said method preferably further comprising  
5 selecting progeny with a total raw protein content of its tubers higher than detected in said first parent and said second parent.

In a further preferred embodiment, the invention provides a method for breeding and selecting a potato with an increased capacity to produce harvestable protein comprising crossing a first parent potato with at least one *amf*-allele with a

10 second parent potato without an *amf*-allele, and selecting progeny (preferably homozygous for the *amf*-allele) by testing it for the presence of at least one *amf*-allele and testing it for coagulating protein content with a method comprising determining total raw protein and total soluble raw protein remaining in solution after a protein coagulation procedures, such as immersion in a boiling water bath  
15 as described herein, to determine or calculate total coagulating protein content of its tubers and selecting progeny with a total coagulating protein content higher than detected in said first parent or said second parent, said method preferably further comprising selecting progeny with a total coagulating protein content of its tubers higher than detected in said first parent and said second parent.

20 Furthermore, the invention provides a potato selected with a method according to the invention, use of a potato as provided herein for the industrial production of starch and/or protein and use of a potato as provided herein in breeding and selection programmes of potatoes. In particular, the invention provides use of a potato plant or part derived thereof having at least one *amf*-allele in a breeding  
25 and selection programme directed at providing potatoes with an increased protein content.

Figures 1 to 4.

30 Examples of breeding schemes for breeding and selecting potatoes

Detailed description



Using an amylose-free (*amf*) mutant of diploid potato (*Solanum tuberosum*), diploid and tetraploid clones with different genotypes at the *amf*-locus were produced. In order to make use of the diploid material in analytic breeding of *amf*-potatoes, clones were selected that produced considerable frequencies of 2n-pollen and 2n-eggs. Successful attempts were made to select normal synaptic as well as desynaptic clones producing 2n-gametes. When for example microspores are stained with a potassium iodide solution (Lugol), starch is stained red in mutants (comprising only the *amf*-gene) and dark blue in the wild type (comprising only the *Amf*-allele). Based on the phenotype of starch in the microspores, tetraploid clones with nulliplex, simplex, duplex, triplex and quadripix genotypes at the *Amf*-locus were selected. We investigated starch properties and protein content in various parts of the mutant potato plant. Starch composition and protein content in tubers turned out to be an easily scorable feature. It allows in breeding programmes for amylose-free potatoes an early assessment of starch and/or protein composition in the prospective plants or parts thereof.

*Plant material.* Monoploid amylose-free (*amf*) clone 86.040 and the parent clone AM79.7322 are described in Hovenkamp-Hermelink et al. (1987, *ibid*). Doubled *amf*-plants were obtained by adventitious shoot regeneration on leaf explants, which were taken from *in vitro* propagated shoots of monoploid 86.040. After root induction in MS<sub>30</sub> (Murashige & Skoog, 1962, *Physiol. Plant* 15:473-497) (MS) medium supplemented with 30 g/l sucrose) a number of these diploid *amf*-plants were transferred into a glasshouse, at 19°C at day: 17°C at night and 16 h daylength, in sterilized leaf containing soil. For better flowering, part of the doubled plants was grafted onto tomato rootstock. Pollen fertility was estimated, after aceto carmine staining. For the crosses, a variety of wild-type potato pollen was used. The crosses were made on open flowers of diploid (2x) clones of 86.040. The wild-type potato clones had been selected for good male and female fertility and 2n-gametes (unreduced gamete) production in male and female parents.

This resulted in breeding material with better fertility both on male and female side giving opportunity to make crosses with more advanced diploid breeding material. From these crosses diploid as well as tetraploid progeny (4x) was obtained. Diploid material was segregating for the *amf*-allele, resulting in 25%

homozygous plants, which could be selected by colouring the tubers with a iodine solution. Also some tetraploid progeny could be obtained as a result of unreduced pollen and unreduced eggcells in both parents. This bilateral sexual

polyploidization has also been used in a third cycle of crosses, making use of  
 5 diploid homozygous amf-clones. A second method to achieve tetraploid progeny has been  $4x.2x$  crosses, where only the pollendonor has to form unreduced gametes to get a tetraploid progeny (unilateral sexual polyploidization).

In general the first two or three cycles of this breeding program have been used to produce male and female fertile amf-breeding material, on the diploid level

10 with the ability to produce unreduced gametes, as a start for a breeding program on diploid and tetraploid chromosomal level. In these breeding cycles also properties as tuber shape, number of tubers and starch content were observed, but no stringent selection was carried out.

From the third cycle onwards crosses have been made between homozygous  
 15 tetraploid amf-clones with existing tetraploid starch potato varieties. From these varieties genetic variation with respect to total starch production and resistance against diseases (potato cyst nematode, late blight, wart disease) was introduced. In the second cycle of these crosses made for agronomic improvement segregation of homozygous recessive amf-clones was expected and colouring of  
 20 tubers with iodine solution was carried out. As a result of this breeding program some agronomical acceptable clones were produced, which are both useful for the large scale production of amylosefree potato starch and as crossing parents in  $4x.4x$  and  $4x.2x$  crosses.

25 *Starch analysis.* Starch granules in micropores and tubers were stained with  $I_2$ -KI solution according to Hovenkamp-Hermelink et al. (1987), in stomatal guard cells and other leaf cells according to the treatment described for, microspores and in root cap cells by treatment of root tips with a mixture of Lugol's-solution and chorallhydrate (1:1, v/v). Four gram of chorallhydrate is dissolved in 2 ml of  
 30 water. The amylose percentage in starch solutions of tubers was measured according to Hovenkamp-Hermelink et al., 1988, Potato Res. 31:241-246). Roottips were fixed and stained according to Pijnacker and Ferwerda (1985, Can. J. Genet. Cytol. 26:415-419) for chromosome counts and karyotypic  
 35 investigations. When for example microspores are stained with a potassium iodide solution (Lugol), starch is stained red in mutants (comprising only the

*amf*-gene) and dark blue in the wild type (comprising only the *Amf*-gene) (Jacobsen et al., 1989, *Euphytica* 44:43-48).

## 5 *Protein analysis*

For determining raw and coagulated protein content, 300 grams of tuber material together with 1000 ppm sodium bisulphite was grinded in a laboratory blender, type Waring Blendor. To determine the dry matter content an homogeneous sample of approx. 10 gram was taken and dried overnight at 40°C. The rest of  
 10 sample was centrifuged for 10 min at 4600 rpm. Of the supernatant raw protein content was determined by determining nitrogen content with the Kjeldahl method and dry matter by overnight drying at 40°C. To determine the coagulated protein content in the supernatant the pH was adjusted to 5.2 with 19% HCl and the liquid was boiled for 1 minute. Subsequently, the samples were centrifuged  
 15 for 10 min at 10000 rpm. To remove the light substance the above liquid was filtered over an S&S 595 paper filter. Nitrogen content of the supernatant after the coagulation step was determined by the Kjeldahl method. All experiments were carried out in duplicate.

20

Raw and coagulated protein content was calculated as follows:

$$\text{Contribution of juice} = \frac{100 - \% \text{DrySubstancePulp}}{100 - \% \text{DrySubstanceJuice}}$$

$$\text{Raw protein} = \text{N total} \times \text{contribution juice} \times 1.5 \times 0.88 \times 6.25$$

$$\begin{aligned} 25 \quad \text{Coagulated protein} &= (\text{N total} - \text{N after coagulation}) \times 6.25 \times \text{contribution juice} \times \\ &1.5 \times 0.88 \\ &(\text{1.5 : dilution factor}) \\ &(\text{0.88 : correction factor}) \end{aligned}$$

30

*Embryo culture.* Unripe berries were surface sterilized by treatment for 1 minute with 70% alcohol and for 15 minutes with a saturated solution of Ca-hypochlorite, containing a few drops of 1%SDS (sodium dodecylsulphate) solution

per 100 ml. The sterilized berries were cut open aseptically. Ovules were collected and cultured on medium EC2 (MS-medium supplemented with  $1.10^{-5}$  g/l kinetin,  $1.10^{-6}$  g/l LAA, 8g/l agar and 30 g/l sucrose) as defined by Neal & Topoleski (1983, J. Amer. Soc. Hort. Sci. 108:434-438; 1985 J. Amer. Soc. Hort. Sci. 110:869-873) for embryo culture of tomato. During ovule culture, the integument rapidly attained a brown color and was removed; this was followed later by entire excision of the embryo from the endosperm, as described by Haynes (1959). The excised embryos were also cultured on medium EC2, at 23°C and 16 h light. The rescued plantlets were propagated and rooted in MS<sub>30</sub>.

10

## Results

### *Identification of amf-gene mutants*

Based on iodine staining of microspores, genotypes corresponding to nulliplex (no wild-type GBSS-allele), simplex, duplex and triplex/quadruplex for the wild-type GBSS allele were selected. This selection was according to the expected segregation presented in Table 1.

Table 1. The expected and obtained offspring when duplex plants (AAaa x AAaa) are crossed. These genotypes can be distinguished after iodine staining by their segregation of blue and red microspores; triplex (AAAa) and quadruplex (AAAA) plants were taken in one group. Genotypes with enough tubers to perform a field trial were selected.

25	plant genotype	chance	microspore segregation blue:red	number of genotypes found <sup>a</sup>	number of gynotypes selected
30	aaaa	1/36	0:1	3	2
	Aaaa	8/36	1:1	20	10
	AAaa	18/36	5:1	33	11
	AAAa	8/36	1:0	19	6
35	AAAA	1/36	1:0		

a:  $\chi^2_{(1:8:18:9)} = 1.62 < 7.82$  which indicates that the offspring is not deviating from the expected 1:8:18:9 segregation of the gene-dosage genotypes for the wild-type GBSS allele.

5

Starch granules of the duplex and triplex/quadruplex genotypes were completely blue. In some of the simplex genotypes however, a small outer layer was red in a small percentage of the starch granules. A number of tuberising plants belonging to each gene-dosage group was selected for further research in a field trial (Table

10 1).

Table 2. The coagulated protein content analysis of offspring when duplex plants (HZ91-RUG-025 x HZ91-RUG-075) are crossed. These genotypes were distinguished after iodine staining by their segregation of blue and red microspores; triplex (AAAa) and quadruplex (AAAA) plants were taken in one group.

15

20

25

plant genotype	No. individuals	mean	S.E.
aaaa	15	1.51**	0.08
Aaaa	15	1.22	0.05
AAaa	17	1.10	0.12
AAAa	25	1.24	0.07
AAAA			

---

\*\*indicates statistically significant effect  $P < 0.05$

30

35

Table 3. The coagulated protein content analysis of offspring when duplex plants (S90-1103 x S90-1101-0004) are crossed. These genotypes were distinguished after iodine staining by their segregation of blue and red microspores; triplex (AAAa) and quadruplex (AAAA) plants where taken in one group.

	plant genotype	No. individuals	mean	S.E.
10	aaaa	8	1.67**	0.08
	Aaaa	13	1.38	0.07
	AAaa	17	1.25	0.12
	AAAa	29	1.46	0.03
	AAAA			

15 \*\*indicates statistically significant effect  $P < 0.05$

#### *GBSS-protein content*

The amount of GBSS-protein in the starch granule of different genotypes was analyzed. Fig. 1 clearly shows that the *amylose-free* plants had no GBSS in the starch granules, however no significant difference could be observed in the GBSS-protein level of the other groups indicating that no dosage effect existed at the protein level. No differences in starch granule size and amylopectine and sucrose content of the tubers were found (data not shown)

#### *Overexpression of heterologous protein in amf mutant*

The invention furthermore provides a transgenic potato cell with at least one *amf*-gene having been provided with a nucleic acid encoding a proteinaceous substance, a sink protein. In a preferred embodiment, said cell accumulates said sink protein up to more than 2%, preferably 4%, or even more than 5% to more than 7% of the total protein content of said cell. The protein preferably contains a high content of essential amino acids (preferably methionine, cysteine, lysine, threonine, or tryptophane). To allow for an enhanced incorporation of these essential amino acids into a sink protein fraction of the *amf* potato cell said cell is provided with one or more gene constructs or nucleic acid molecules encoding at least one functional enzyme related to said amino acid's biosynthesis pathway allowing said cell to increasingly synthesise said amino acid, preferably wherein

said amino acid is an essential amino acid and thereby further regulates supply. Preferably, free amino acid level is increased by introducing at least one gene encoding a feedback insensitive enzyme involved in biosynthesis of said amino acid. The over-produced free essential amino acids are trapped by incorporation  
 5 in a sink protein, rich in said essential amino acid, that is expressed at the same time in the plant.

As food or feed organisms, or tissues, differ in limiting essential amino acids, the optimal amino acid content for a sink protein varies according to organism. A  
 10 sink protein preferably is a protein specifically enriched in those amino acids for which a deficit occurs in the specific crop or organism. By producing the sink protein to at least 2%, preferably to at least 4%, 5%, or even at least 7% of the total protein content of the tissue which is being used as food or feed, we compensate for the essential limiting amino acid. For example, for potato a sink  
 15 protein preferably contains at least 5%, more preferably at least 10% lysine, at least 2.5% methionine, at least 2.5% cysteine, or at least 1.5% tryptophan.

The protein is stable in the plant, accumulates to high levels and has no drastic detrimental effects on the growth and physiology of the crop plant. The protein is  
 20 well digestible by the livestock and/or human digestive tract.

Sink protein candidates can for example be selected from among known storage proteins. Several publications describe the amino acid composition of plant storage proteins, and their possible use to enhance the essential amino acids  
 25 composition of food and feed crops. The storage proteins of cereal crops like wheat, barley and maize of the so-called prolamin type vary in their content of sulphur-containing amino acids (methionine and cysteine). Some are relatively high in S-rich amino acids. However, most of them are severely deficient in lysine and tryptophan (Shewry, P. R., (1998) Transgenic Plant Research, p.135-149).  
 30 The storage proteins in legumes and other dicotyledons are mainly of the globulin family or the albumin family. Globulins are generally very poor in the sulphur-containing amino acids, but sometimes do contain a relatively high ratio of lysine. Vicilin (of *Vicia faba*) has a lysine content of 7.2%, threonine content of 3% and a methionine content of only 0.2%. The 2S albumin family of storage proteins in  
 35 general have a high content of S-rich amino acids. Brazil nut 2S albumin

contains ca. 26% sulfur amino acids (Ampe 1986), and sunflower 2S albumin (Sfa8) contains 24% sulfur amino acids (Kortt 1991). Other storage proteins that have a high content of lysine residues are the protease inhibitors C1 and C2 from barley (9.5% and 11.5% lysine respectively, Hejgaard and Boisen (1980)) and the  
 5 cysteine protease inhibitor multicystatin of potato (Waldron et al., 1993 Plant Mol Biol. 23(4):801-12).

The level of protein accumulation in a plant is determined by the rate of synthesis in relation to the rate of degradation of this protein. The rate of  
 10 degradation is determined by its sensitivity to attack of proteases that are present in the producing tissue. This protease sensitivity is influenced by the availability of susceptible sequence domains on the surface of the protein, in combination with the structural rigidity of the protein. In order to select for a protein that will have a high chance to accumulate in the plant, the protein  
 15 preferably has a rigid tertiary structure, with minimal exposed sequence domains. Certain proteins have a native tendency to aggregate into more or less regular or organised macromolecular structures, such as protein bodies or protein crystals. Naturally, storage proteins that accumulate in plant tissue, where they have a storage function, are naturally adapted to remain stable in these plant  
 20 tissues. Therefore seed storage proteins are distinct candidates to accumulate essential amino acids. However, few plant storage proteins will always have a desired composition relating to the desired essential amino acids. Furthermore, in general the amount of essential amino acids is often too low. The invention herewith provides using sink protein that is encoded by a nucleic acid enriched  
 25 with the necessary codons encoding said desired amino acids. In addition to this, in nature several proteins exist that form (semi)-crystalline structures in their natural tissue. Examples are some peroxisomal proteins like alcohol oxidase or urate oxidase, or crystallins (eye lens proteins). Also plant structural proteins are able to form regular crystal like structures, for example the cysteine protease  
 30 inhibitor multicystatin present in the peel of potato.

As an example the use of a combination of gene constructs containing a DNA sequence encoding an enzyme having dihydrodipicolinate synthase (DHPS) activity combined with a DNA sequence encoding a sink protein that is rich in  
 35 essential amino acids, e.g. multicystatin, is provided. First half of this construct



containing the DHPS genes results in an increased level of free lysine more than 10-fold the wild type level of each amino acid in a plant or parts thereof. The expression regulation should be such that expression occurs in such a way that lysine are produced to a comparable extent without damaging the plant i.e.

5 without causing negative aberrations in the phenotype compared to wild type plants. The second part of this combination of gene constructs consists of a gene encoding a sink protein, which contains a high amount of essential amino acids. This sink protein results in an increased incorporation of essential amino acids into the protein fraction. As such it withdraws these amino acids from the pool of  
10 free amino acids, thus further enhancing the synthesis of these essential amino acids.

#### Example 1. Chimeric gene construct with the mutant potato DHPS gene

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DNA isolation, subcloning, restriction analysis and DNA sequence analysis is performed using standard methods (Sambrook, J. et al. (1989) *Molecular Cloning. A laboratory manual*, Cold Spring Harbor Laboratory Press; Ausubel, F.M. et al. (1994) *Current protocols in molecular biology*, John Wiley & Sons).

20

In order to create a feedback insensitive DHPS, the evolutionary conserved amino acid residue 134 (asparagine) were changed into a cysteine residue (WO0148230). The mutant DHPS encoding DNA fragment (designated DHPS-134nc1) was used for the expression in potato plants.

25

The chimeric gene containing the mutant DHPS gene was constructed by subcloning DHPS cDNA from the pTriplex vector in pCR-Script SK(+) and from this vector as a XbaI-Eco RI fragment in the pBluescript SK vector digested with XbaI-EcoR. With this clone the mutagenesis was performed, resulting in clone pAAP57-134nc1. At the 5'end the mutated DHPS cDNA was fused to a HindIII-

30

SalI fragment of the 800 bp long GBSS promoter fragment (Visser et al. *ibid*).

Downstream of the mutant DHPS sequence the termination signal of the nopaline synthase gene from *Agrobacterium tumefaciens* was inserted (Greve, H.D. et al. (1983) *J.Mol.Appl.Genet.* 1: 499-511) as an SstI-EcoRI fragment. The complete chimeric gene was subcloned into the HindII-EcoRI sites of pBINPLUS

35

(Van Engelen, F.A. et al. (1995) *Transgenic Research* 4: 288-290) (pAAP105).

The binary vector pAAP105 was used for freeze-thaw transformation of *Agrobacterium tumefaciens* strain AGLO (Höfgen, R. and Willmitzer, L. (1988) Nucl.Acids Res. 16: 9877). Transformed AGLO was subsequently used for

5 inoculation of potato (*Solanum tuberosum*, variety Kardal) stem explants as described by Visser (Visser, R.G.F. (1991) Plant Tissue Culture Manual B5 (ed. by K. Lindsey): 1-9, Kluwer Acad. Publishers, The Netherlands). After shoot and root regeneration on kanamycin-containing media plants were put in soil and transferred to the greenhouse. Plants regenerated (on kanamycin-free media)

10 from stem explants treated with the *Agrobacterium* strain AGLO lacking a binary vector served as a control.

#### Example 2 Overexpression of the potato multicystatin gene

15 The Potato Multicystatin (hereinafter PMC) gene encodes a multidomain cysteine protease inhibitor protein. A genomic clone of the PMC gene (Waldron et al., (1993) Plant Molecular Biology, 23:801-812) was fused at the 5' end to the omega DNA sequence from the coat protein of tobacco mosaic virus (Gallie, D.R. et al.

20 (1987) Nucl.Acids Res. 15: 3257-3273). Downstream of the PMC sequences the termination signal of the octopine synthase gene from *Agrobacterium tumefaciens* is inserted (Greve, H.D. et al. (1983) J.Mol.Appl.Genet. 1: 499-511). The chimeric PMC gene construct is cloned as a BamHI/SpeI fragment in pBluescript The patatin promoter (Wenzler, H.C. et al. (1989) Plant Mol.Biol. 12:

25 41-50) is ligated as a blunt (HindIII filled in)/BamHI fragment in front of the PMC chimeric gene digested with SmaI/BamHI (pAAP169).

#### Example 3 Transformation of potato plants

30 The binary vector pAAP105 and PAAP169 is used for freeze-thaw transformation of *Agrobacterium tumefaciens* strain AGLO (Hofgen, R. and Willmitzer, L. (1988) Nucl.Acids Res. 16: 9877). Transformed AGLO is subsequently used for inoculation of tetraploid wildtype potato (*Solanum tuberosum*, variety Kardal)

35 and tetraploid *amf* mutant KA96-1396 stem explants as described by Visser

(Visser, R.G.F. (1991) Plant Tissue Culture Manual B5 (ed. by K. Lindsey): 1-9, Kluwer Acad. Publishers, The Netherlands). After shoot and root regeneration on kanamycin-containing media plants are put in soil and transferred to the greenhouse. Plants regenerated (on kanamycin-free media) from stem explants treated with the *Agrobacterium* strain AGLO lacking a binary vector serve as a control.

#### Example 4. Analysis of free amino acid content in transgenic plants

10

Tissue (0.5-1.0 gram) is homogenized with mortar and pestle in 2 ml 50 mM Pi-buffer (pH 7.0) containing 1 mM dithiothreitol. Nor-leucine is added as an internal standard. Free amino acids are partly purified by extraction with 5 ml of a water:chloroform:methanol mixture (3:5:12). Water phase is collected and the remaining re-extracted twice. After concentration by lyophilization to 3 ml, a 20  $\mu$ l sample is analysed by HPLC using a cation-exchange column with post-column ninhydrine derivatisation of the amino acids detected at 570 and 440 nm (BIOCHROM 20, Amersham Pharmacia biotech).

#### 20 Example 5. Coagulated protein content of transgenic plants

For determining raw and coagulated protein content, 300 grams of tuber material together with 1000 ppm sodium bisulphite was grinded in a laboratory blender, type Waring Blendor. To determine the dry matter content an homogeneous sample of approx. 10 gram was taken and dried overnight at 40°C. The rest of sample was centrifuged for 10 min at 4600 rpm. Of the supernatant raw protein content was determined by determining nitrogen content with the Kjeldahl method and dry matter by overnight drying at 40°C. To determine the coagulated protein content in the supernatant the pH was adjusted to 5.2 with 19% HCl and the liquid was boiled for 1 minute. Subsequently, the samples were centrifuged for 10 min at 10000 rpm. To remove the light substance the above liquid was filtered over an S&S 595 paper filter. Nitrogen content of the supernatant after the coagulation step was determined by the Kjeldahl method. All experiments were carried out in duplicate.

35

Table 4**LYSINE RICH**

<b>Vicilin</b>	Fava bean	436aa	32 lys (7.2 %)	storage protein
<b>SCR1</b>	Soybean	102aa	21 lys (20.6%)	stress induced
<b>Fcor 2</b>	Strawberry	133aa	19 lys (14.3%)	cold induced
<b>TLRP</b>	Tomato	62aa	11lys (17.7%)	matrix protein
<b>multicystatine</b>	Potato		11.8% lys	Protease inhibitor

5

**METHIONINE RICH**

<b>γZein</b>	Maize	211 aa	55 met (26.1%)	storage pro
<b>10kDa Zein</b>		150aa	31 met (20.7%)	storage pro
<b>2S albumin</b>	Sunflower	141aa	18 met (12,8%)	storage pro

10

**THREONINE RICH**

<b>TIP13</b>	Asparagus	182aa	23 thr (12.6%)	harvest
<b>PTGRP</b>	Tomato	78aa	16 thr (20.5%)	water stres

**CYSTEINE RICH**

5

<b>PA1b</b>	Pea	130aa	10 cys (7.7%)	storage pro
<b>SE60</b>	Soybean	47aa	8 cys (17.2%)	storage pro
<b>PCP1</b>	Rape Seed	83aa	8 cys (9.6%)	pollen/stign

## Claims

1. A potato plant or part derived thereof having at least one *amf*-gene said potato plant or part further provided with an increased capacity to store a protein as characterized by a protein content of its tubers of at least 1.9% m/m,
2. A potato plant or part according to claim 1 characterized by a protein content in said tubers of at least 2.3% m/m.
3. A potato according to claim 2 characterized by a protein content in said tubers of at least 2.7% m/m.
4. A potato according to anyone of claims 1 to 3 characterized in that it is an amylose-free potato.
5. A potato according to anyone of claims 1 to 4 characterized in that its tubers essentially show a coagulating protein versus starch ratio of at least 45 kg/ton.
6. A potato according to claim 5 showing a coagulating protein versus starch ratio of at least 90 kg/ton.
7. A potato according to anyone of claims 1 to 6 characterized in that it is a transgenic potato.
8. A potato according to claim 7 comprising a heterologous protein.
9. A potato according to claim 8 wherein said heterologous protein comprises a protein listed in table 4.
10. A method for breeding and selecting a potato comprising crossing a first parent potato with at least one *amf*-gene with a second parent potato without an *amf*-gene and selecting progeny by testing it for the presence of at least one *amf*-gene and testing it for protein content and selecting progeny with at least one *amf*-gene with a protein content higher than detected in said first parent or said second parent.
11. A method according to claim 10 further comprising testing for protein content by determining protein content of its tubers or root caps.
12. A method according to claims 10 or 11 further comprising selecting progeny homozygous for the *amf*-gene
13. A potato plant or part derived thereof selected with a method according to anyone of claims 10 or 12.

14. Use of a potato plant or part derived thereof having at least one *amf*-allele in a breeding and selection programme directed at providing potatoes with an increased protein content.

## Abstract

5 The invention relates to the breeding and selection of potatoes. The invention provides a potato plant or part derived thereof having at least one *amf*-allele said potato plant or part further provided with an increased capacity to store a protein as characterized by an increased protein content of its tubers. Furthermore, the invention provides a method for breeding and selecting a potato with an

10 increased capacity to store a protein comprising crossing a first parent potato with at least one *amf*-allele with a second parent potato without an *amf*-allele, and selecting progeny for the presence of at least one *amf*-allele with a protein content of its tubers higher than detected in said first parent or said second parent.

15





KA 91-1021	♀ S 90-1101-0003	♀ S 88-0003-TRCS	♀ RUG 87-1017-0005	♀ 86040
		♂ * CALGARY * (CALGARY)	♂ RUG 87-1016-0001	♂ SH 82-0070-0297
			♀ * HAVILA * (KA 68-1217)	♀ 86040
			♂ AM 66-0042	♂ SH 82-0062-0247
			♀ RUG 87-1017-0005	♀ * MARA * (KA 63-1165)
			♂ * ASTARTE * (KA 68-1503)	♂ KA 63-0600
			♂ AM 66-0042	♀ (VT)* 62-0033-0003
				♂ 19268
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				♀ RR 62-0005-0043
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KA 91-1117	<div>♀ S 90-1103</div> <div>♂ S 90-1101-0004</div>	<div>♀ 88-0004-0006</div> <div>♂ * KARDAL * (KA 76-0271)</div> <div>♀ S 88-0003-7RC8</div> <div>♂ * CALGARY * (CALGARY)</div>	<div>♀ RUG 87-1016-0001</div> <div>♂ E(772102-37)</div> <div>♀ * ASTARTE * (KA 68-1503)</div> <div>♂ AM 66-0042</div> <div>♀ RUG 87-1017-0005</div> <div>♂ RUG 87-1024-0001</div> <div>♀ * HAVILA * (KA 68-1217)</div> <div>♂ AM 66-0042</div>	<div>♀ 86040</div> <div>♂ SH 82-0070-0297</div> <div>♀ SH 82-0062-0247</div> <div>♀ * MARA * (KA 63-1165)</div> <div>♂ KA 63-0600</div> <div>♀ (VTY) 62-0033-0003</div> <div>♂ 19268</div>	<div>♀ 86040</div> <div>♂ SH 82-0070-0297</div> <div>♀ 86040</div> <div>♂ SH 82-0062-0247</div> <div>♀ * MARA * (KA 63-1165)</div> <div>♂ KA 63-0600</div> <div>♀ (VTY) 62-0033-0003</div> <div>♂ 19268</div>
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♀ KA 91-1021	♀ S 90-1102-0006	♂ * KARDAL * (KA 76-0271)	♂ RUG 87-1016-0001	86040 * SH 82-0070-0297
♂ KA 91-1097	♂ S 90-1101	♀ * CALGARY * (CALGARY)	♂ RUG 87-1024-0001	86040 * SH 82-0070-0297
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